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(71) Applicant
Bramleigh Associates Limited

(Incorporated in Irish Republic)

88 O'Connell Street, Limerick, Republic of Ireland

(72) Inventor
John Mallon

(74) Agent and/or Address for Service
Marks & Clerk,
Alpha Tower, Suffolk Street Queensway, Birmingham B1 1TT

(54) Glass object inspection

(57) A method and apparatus for analysing physical features of a glass object. The apparatus comprises a light projector (5) for directing a slit of light at a glass object (2), and an oscillating mirror (7) for directing light reflected from the object in a scanning movement to a linear array camera (10). The apparatus is connected to control and recording equipment (12). The apparatus distinguishes light reflected from different surfaces of the glass object as separate inner and outer images, and analyses these images to determine the physical features of the glass object. The physical features may include thickness, profile and surface irregularity and the presence or absence of faults.

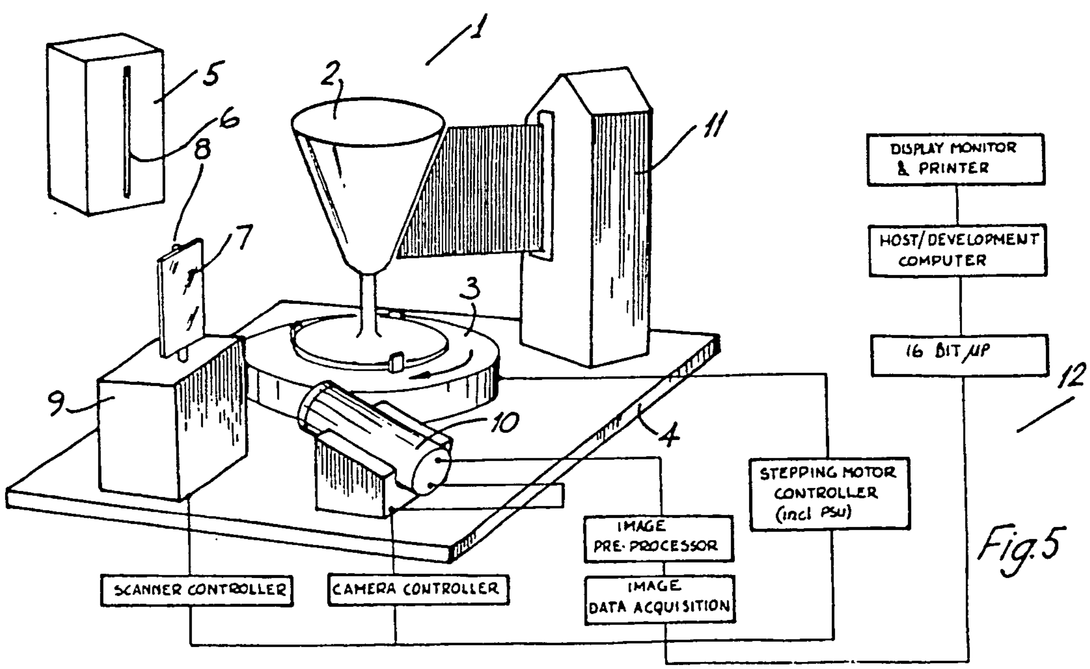

Fig.5

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This print takes account of replacement documents submitted after the date of filing to enable the application to comply with

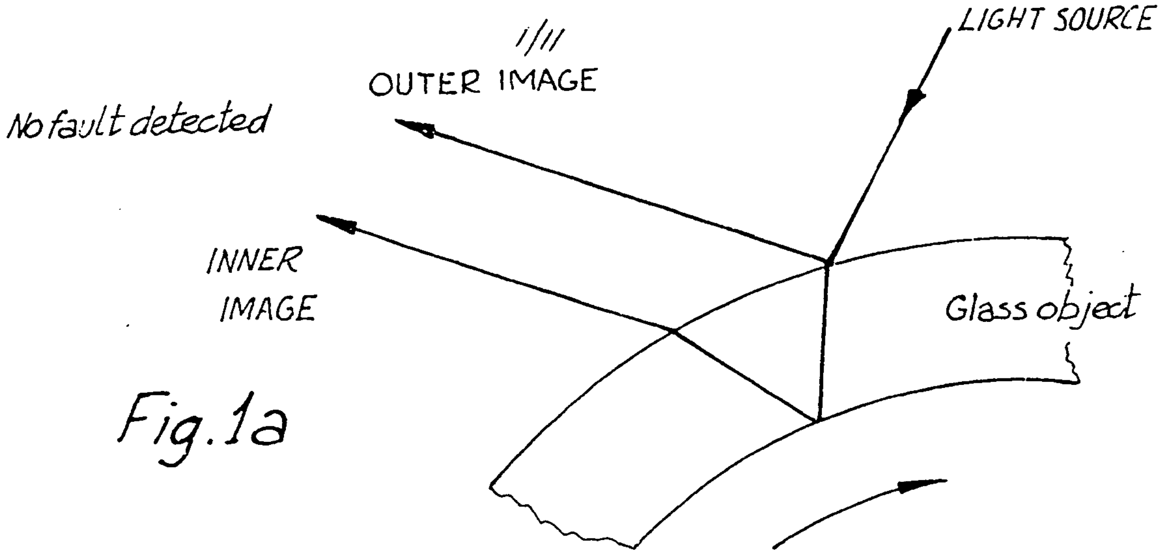

Fig.1a

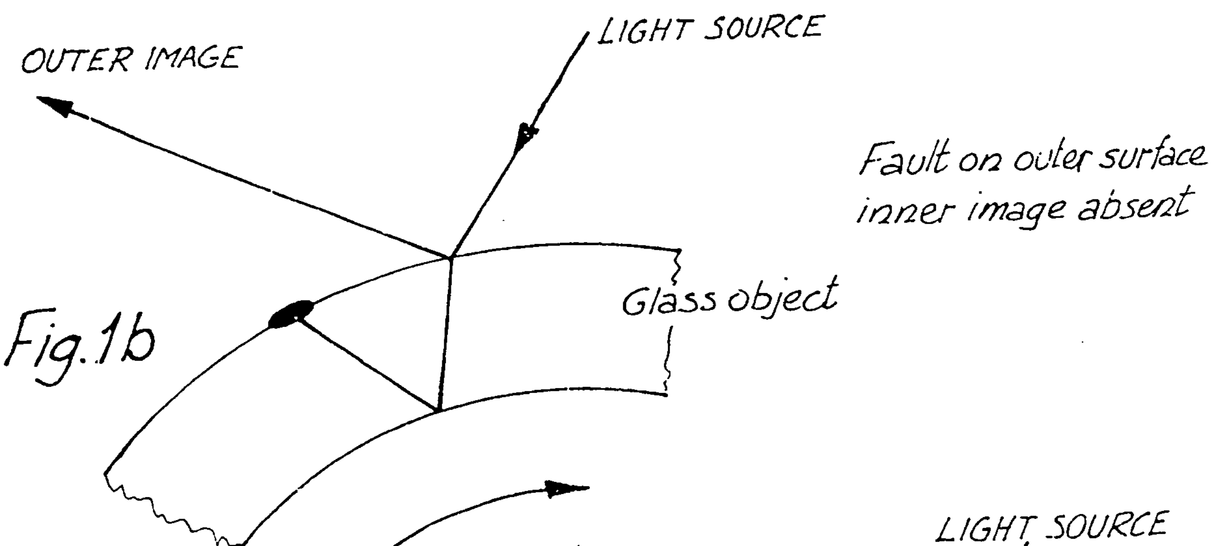

Fig.1b

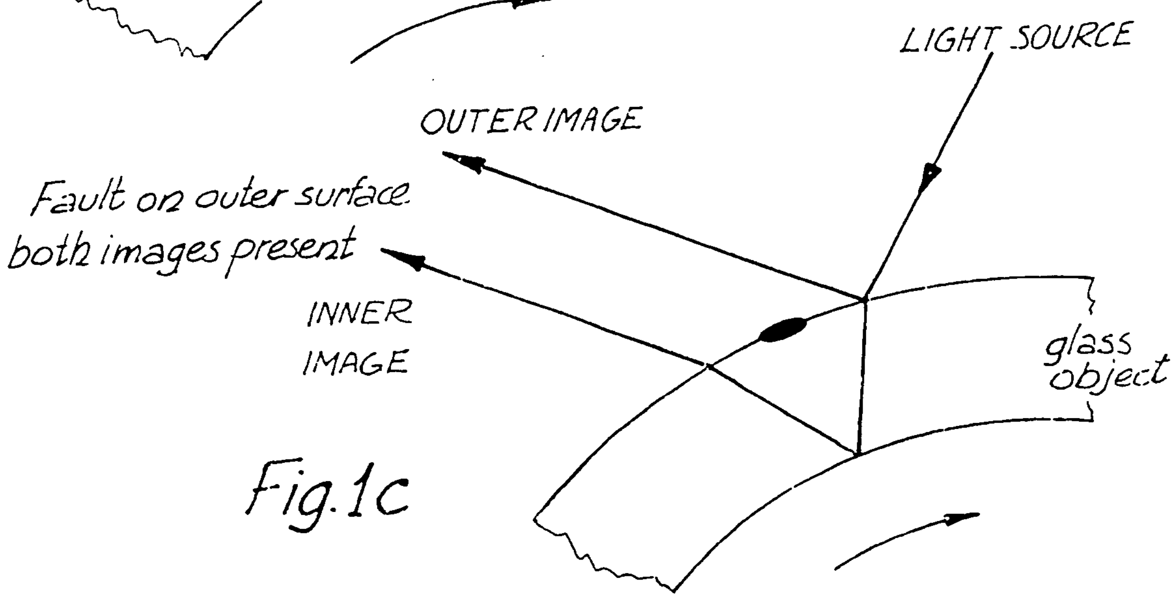

Fig.1c

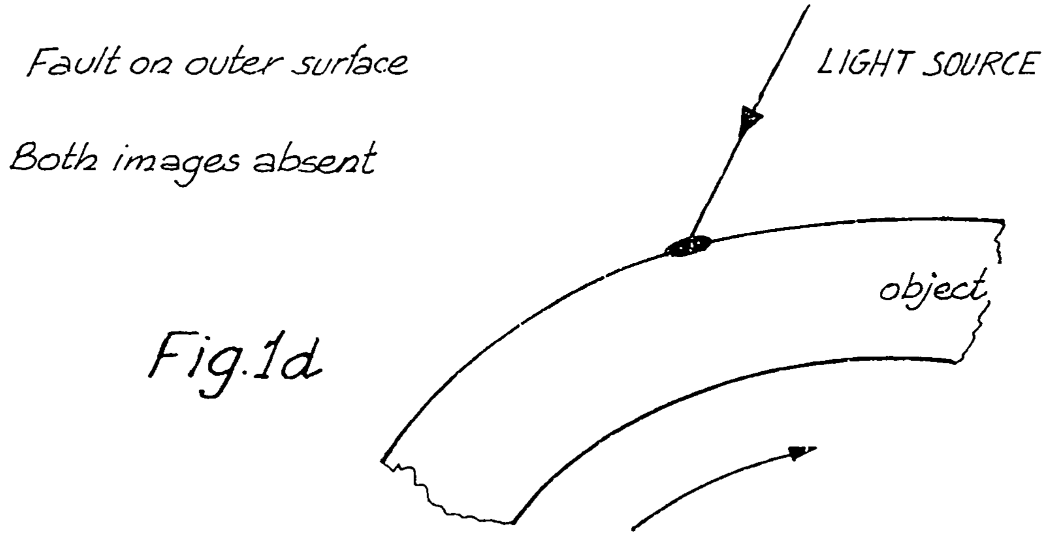

Fig.1d

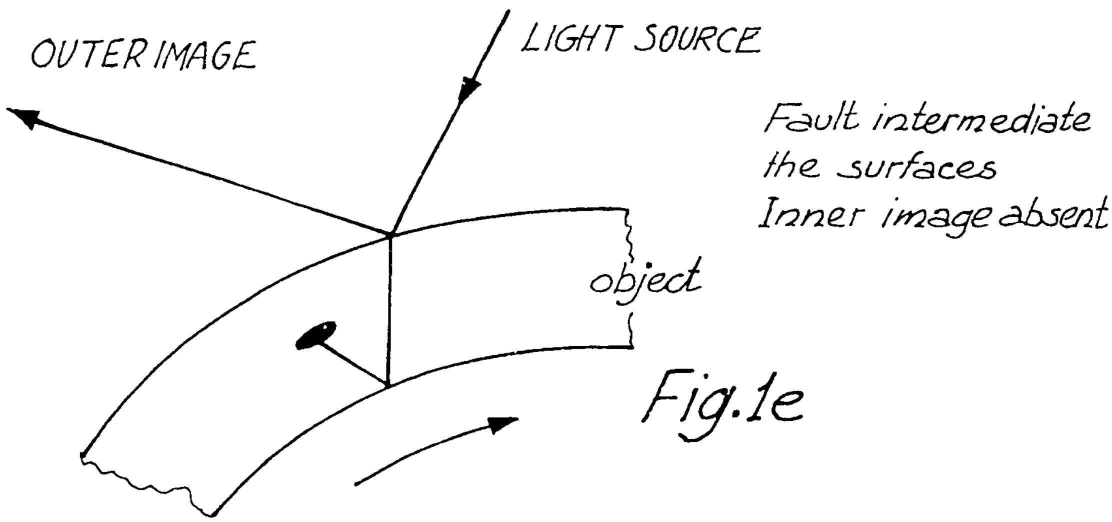

Fig.1e

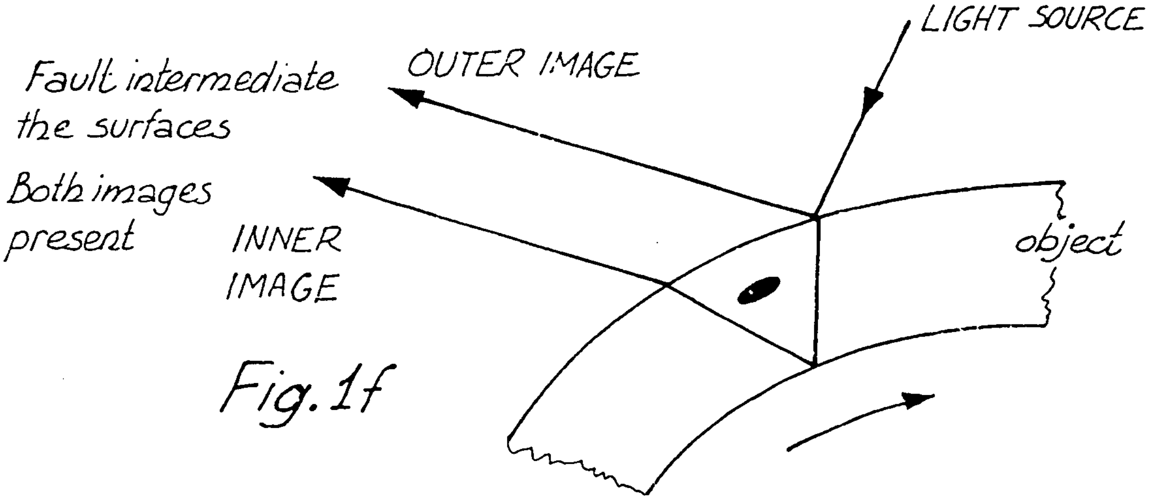

Fig.1f

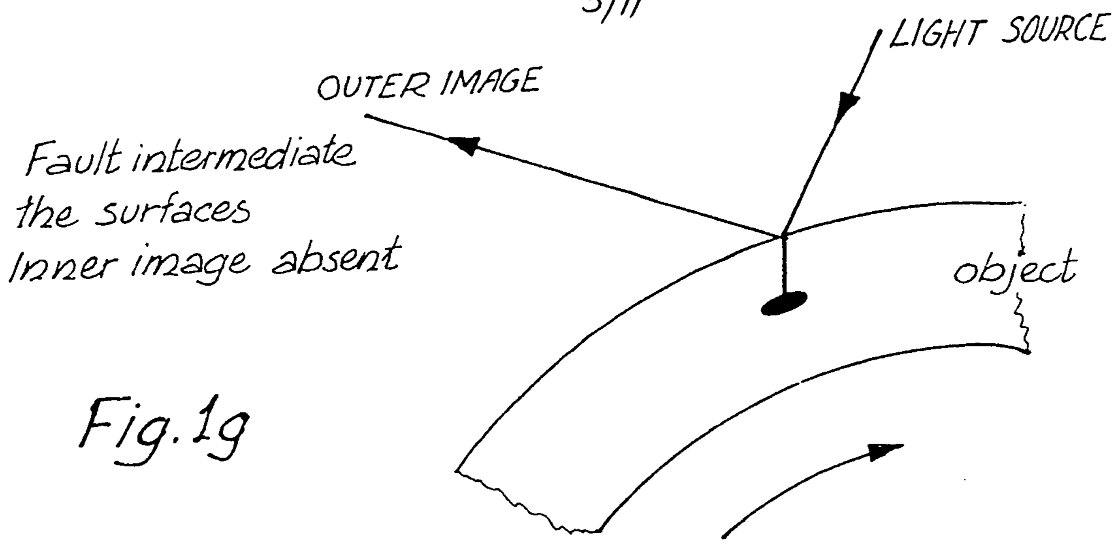

Fig.1g

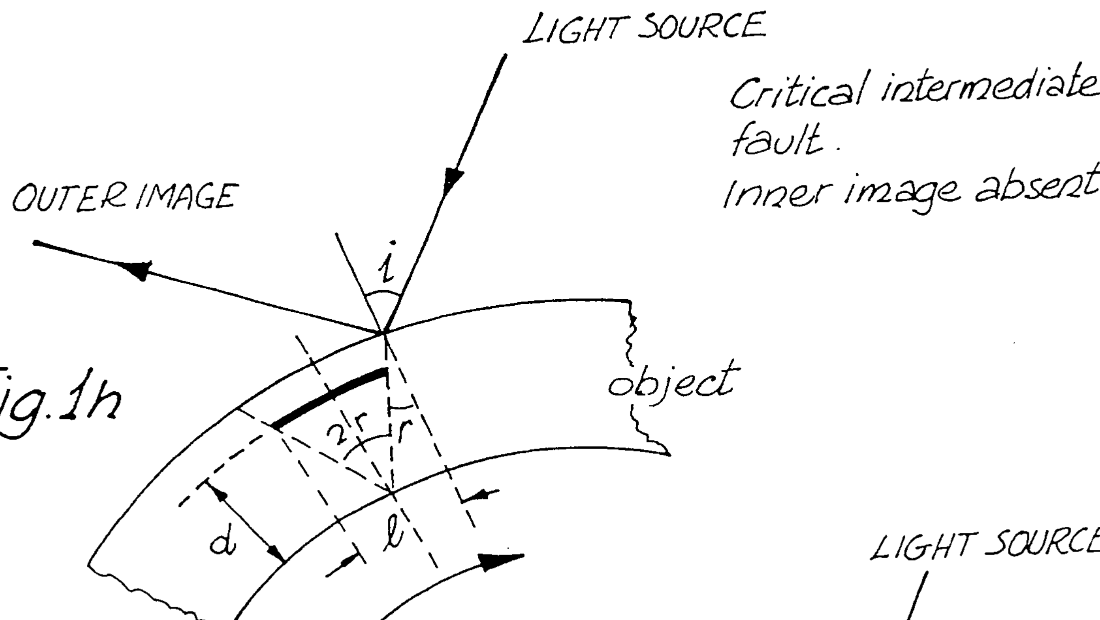

Fig.1h

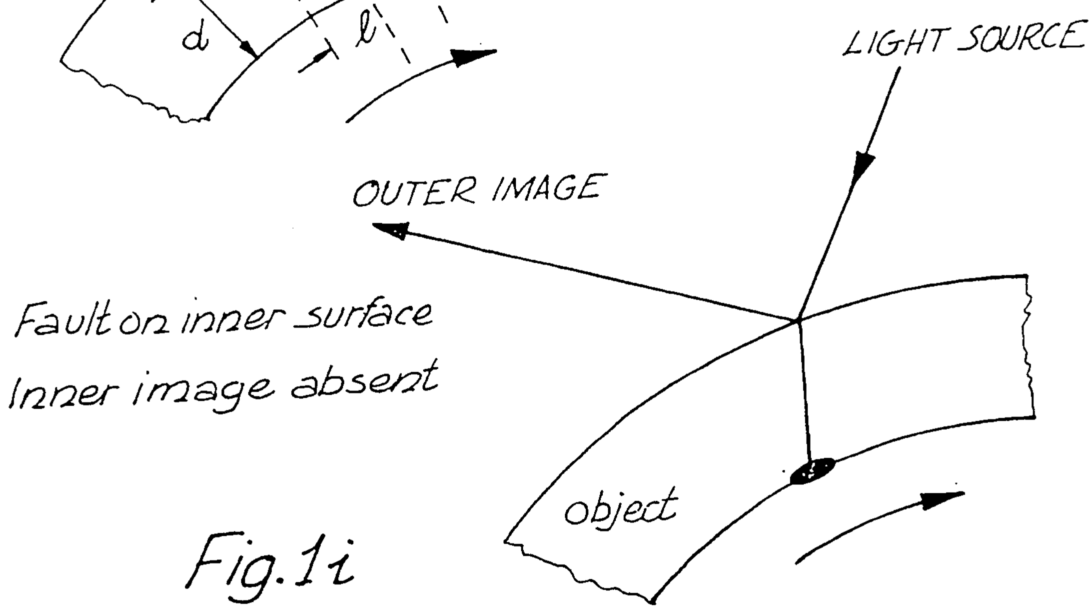

Fig.1i

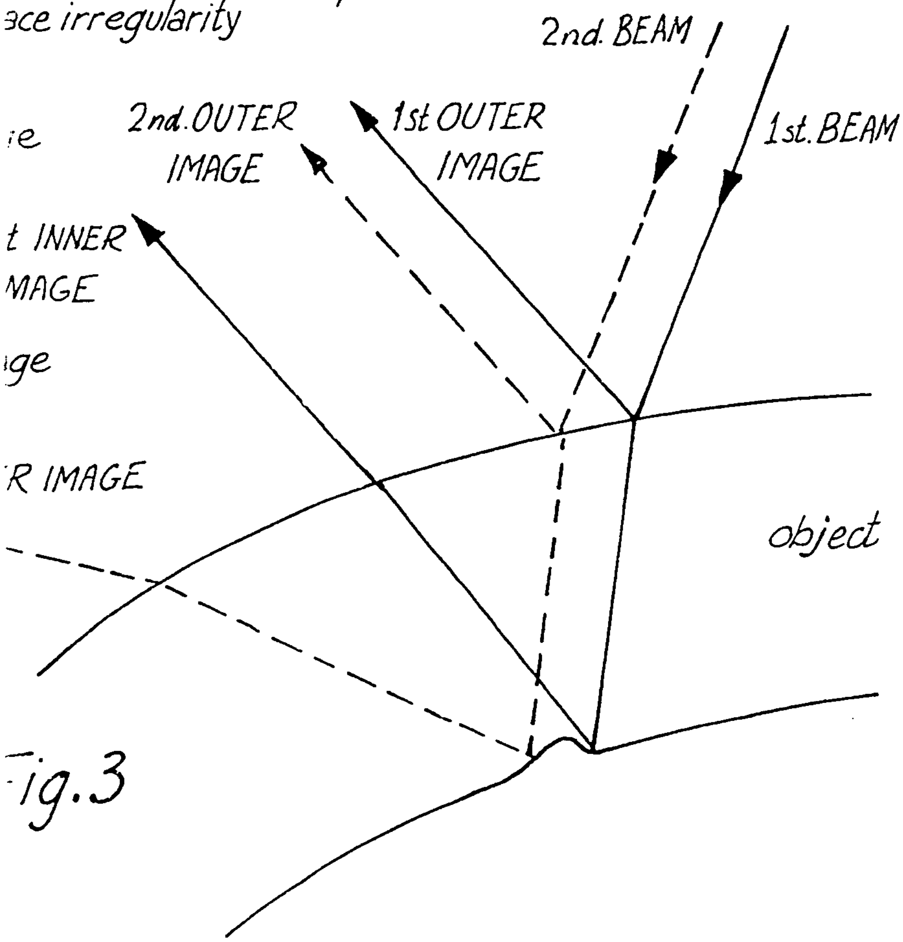
ace irregularity
2nd. BEAM
2nd. OUTER IMAGE
1st OUTER IMAGE
1st. BEAM
ie
t INNER MAGE
ge
R IMAGE
object

Fig.3

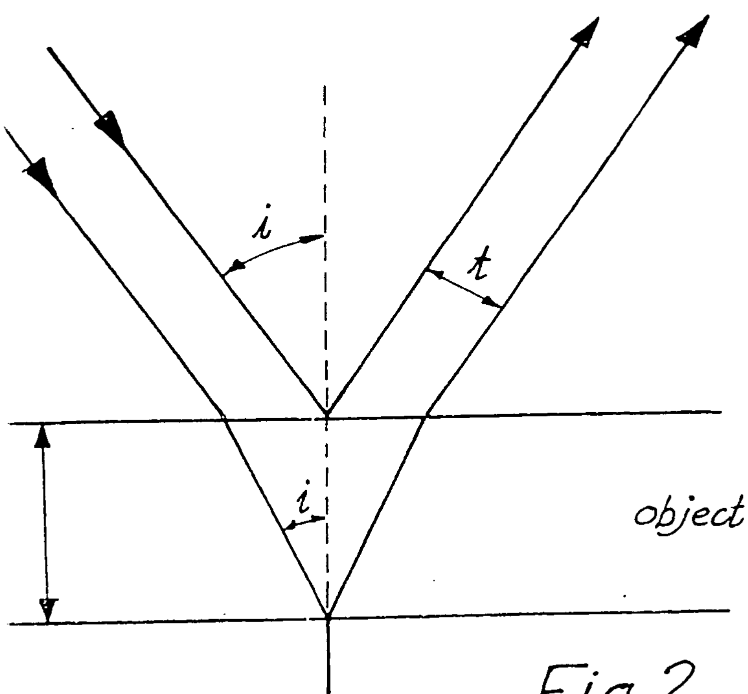
i
t
i
object

Fig.2

Outer surface irregularity

outer and inner images shifted

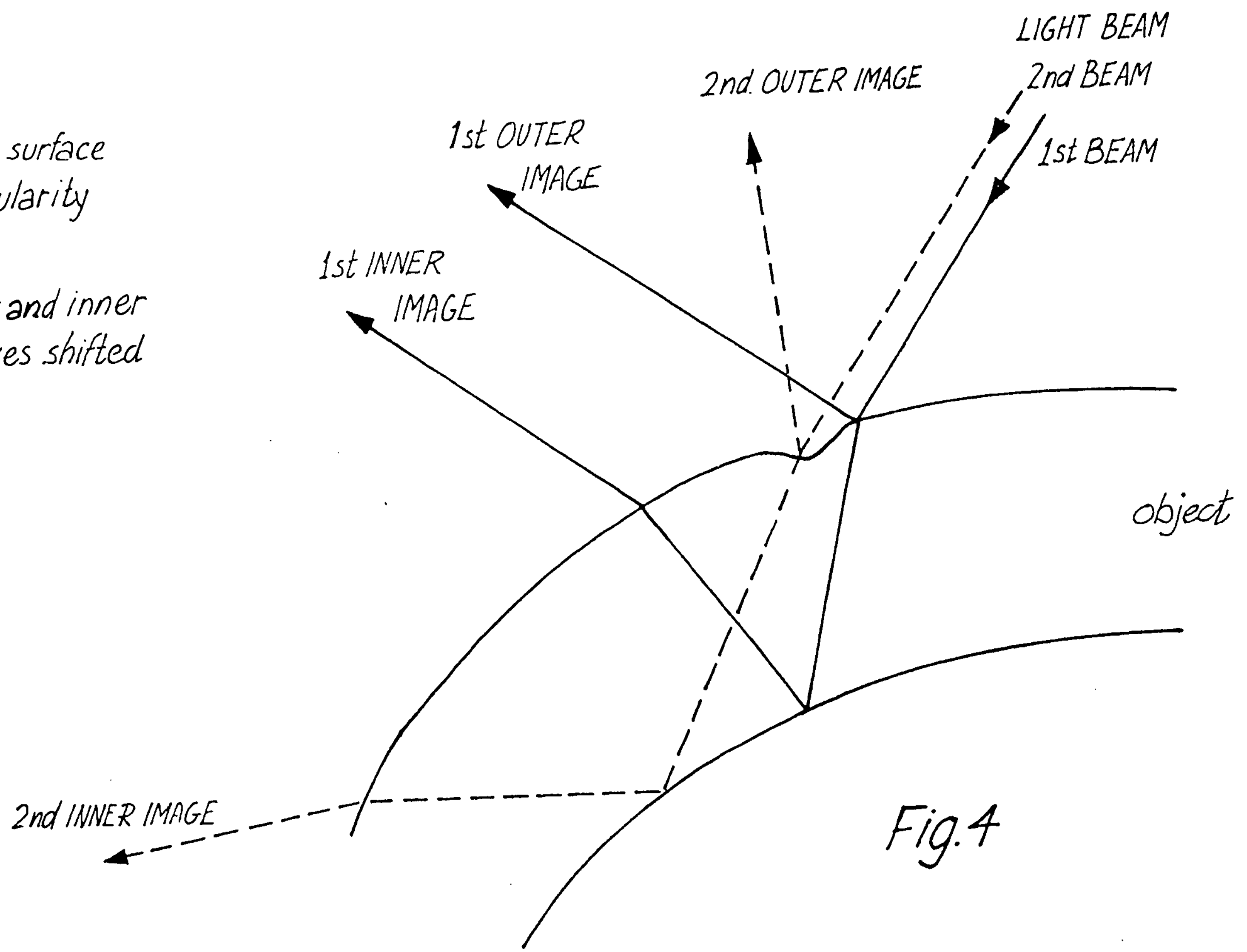

Fig.4

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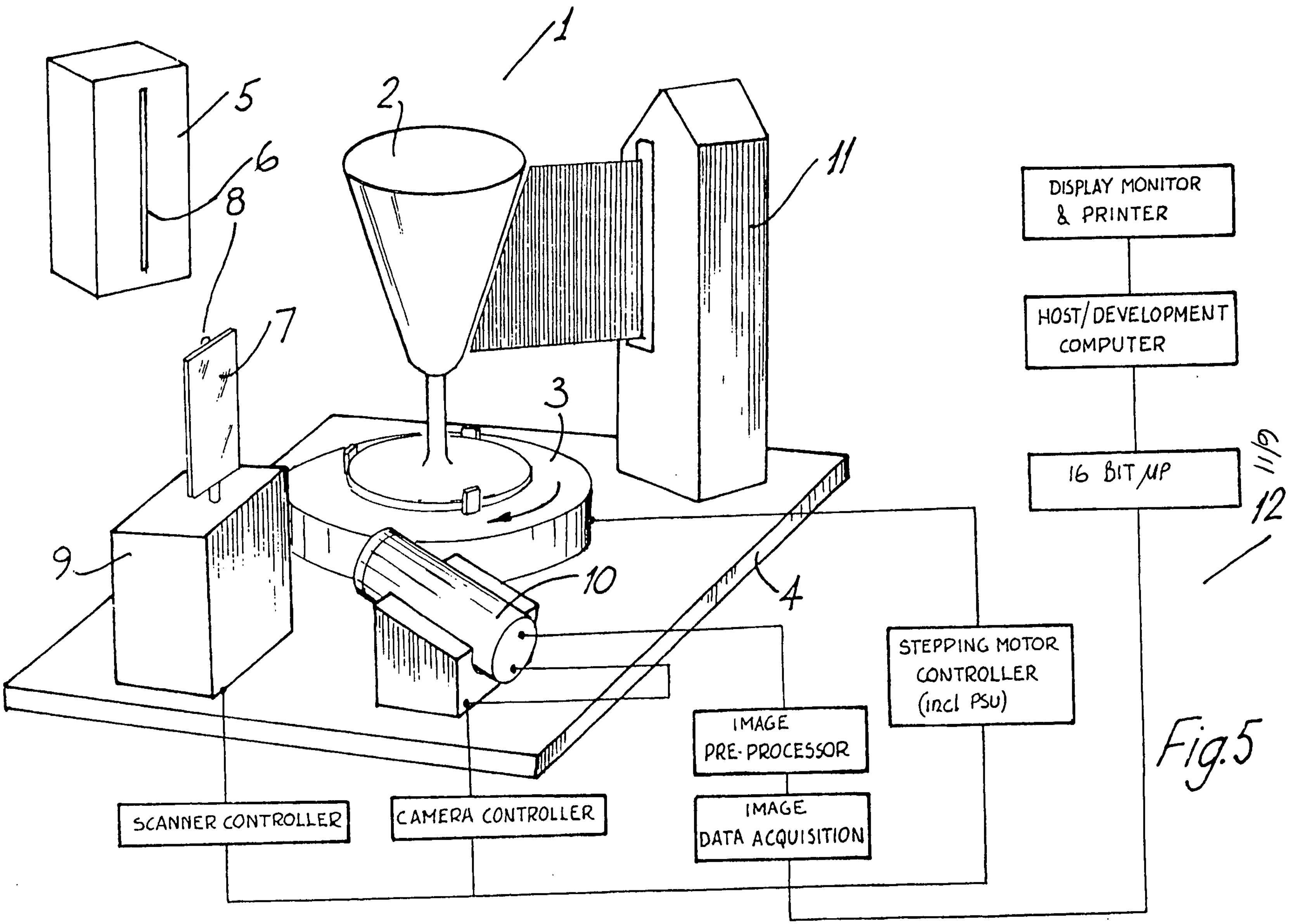


Fig.5

Fig.6

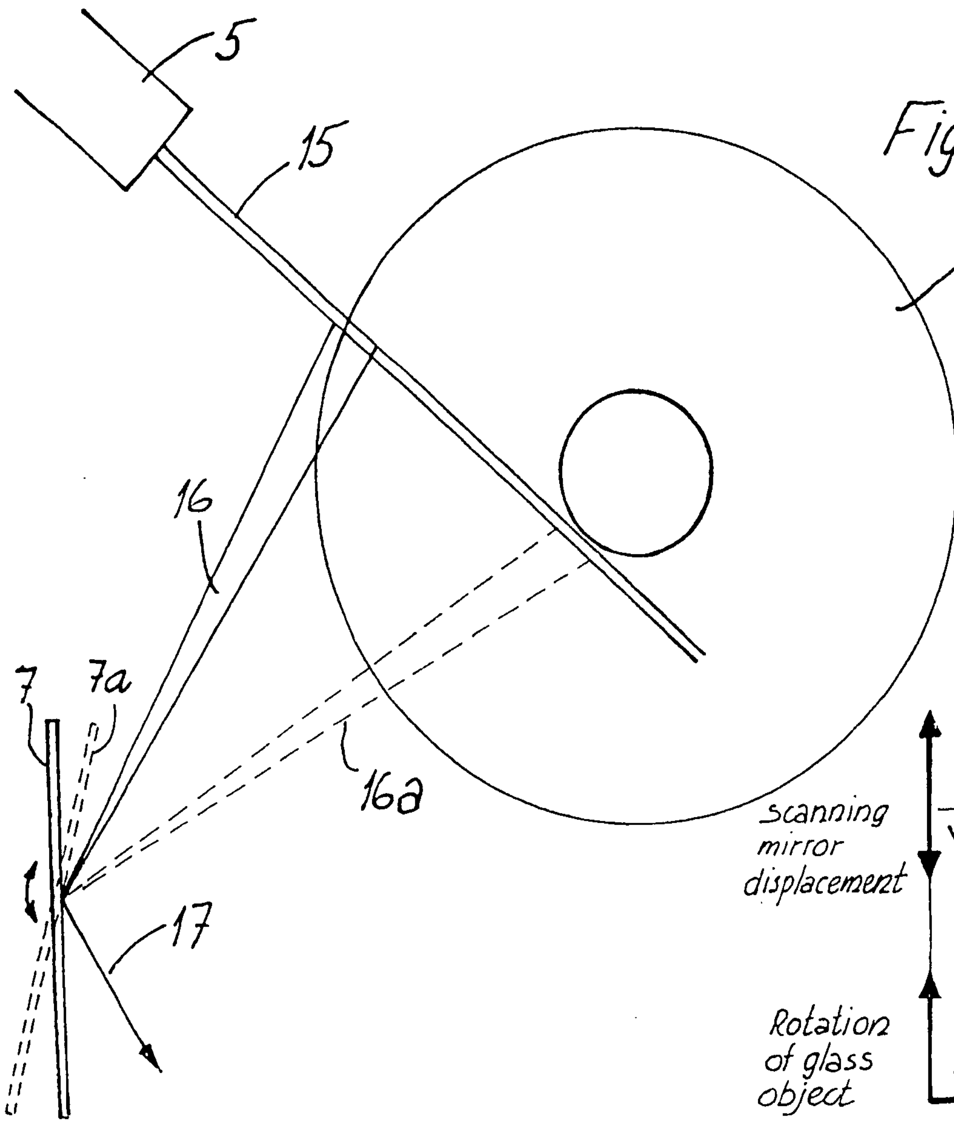
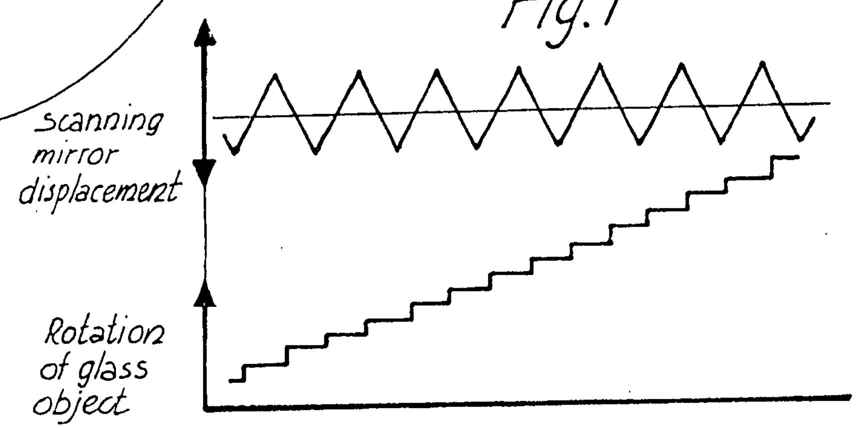

5
15
2
16
16a
7
7a
17

Fig.7


Scanning mirror displacement
Rotation of glass object

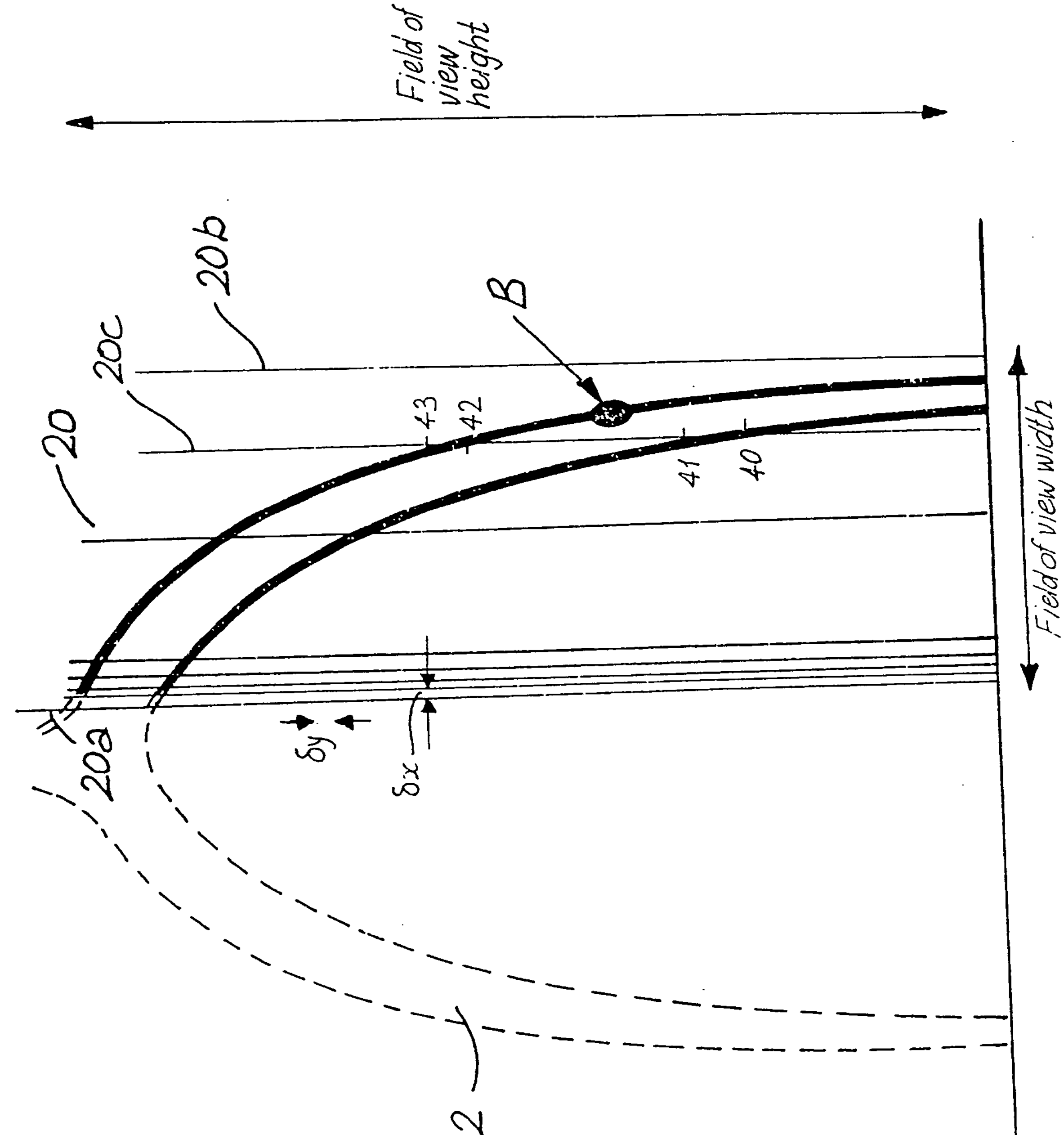

Field of view height
20b
20c
20
B
43
42
41
40
Field of view width
20a
δy
δx
2

Fig.8

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9/11

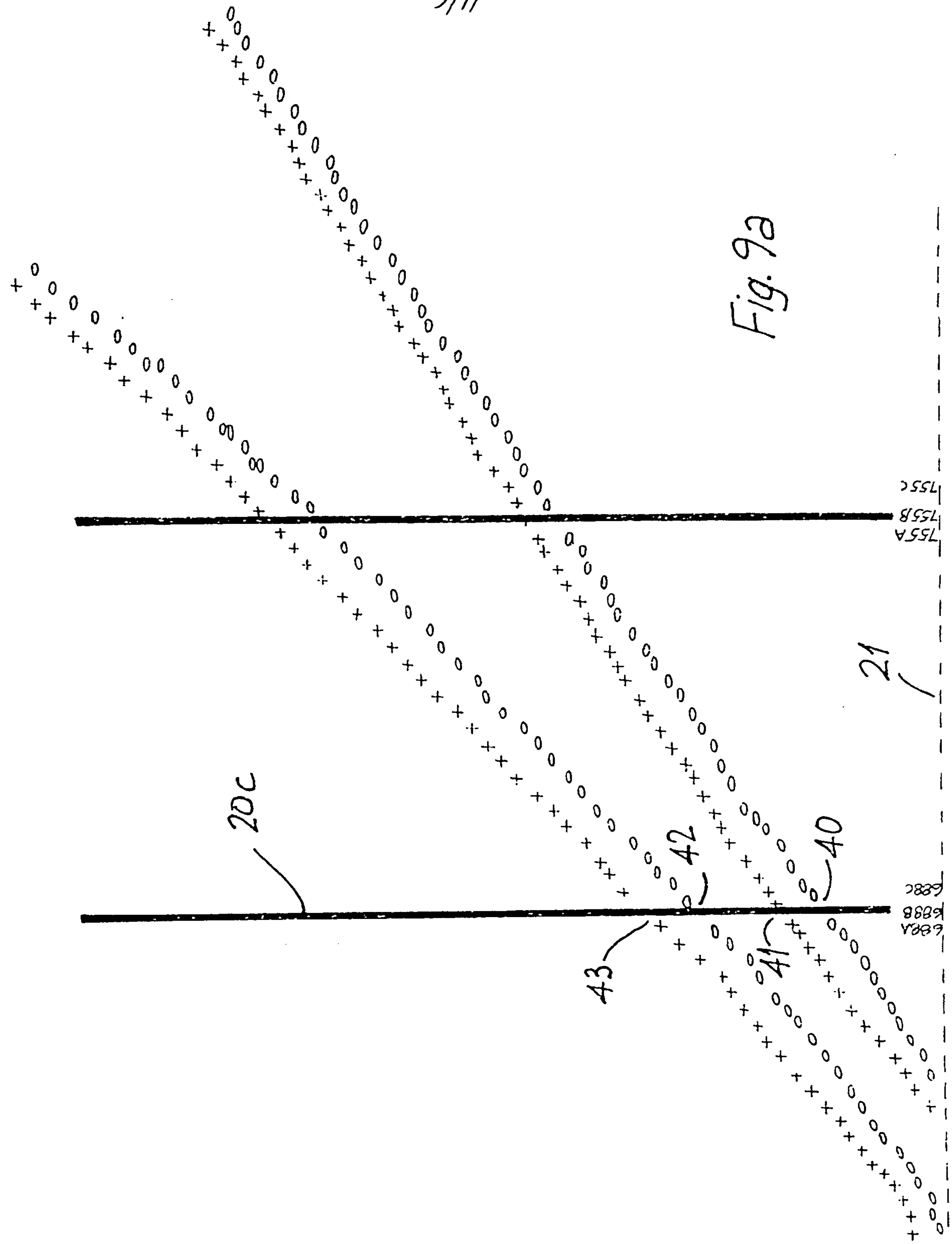

Fig. 9a

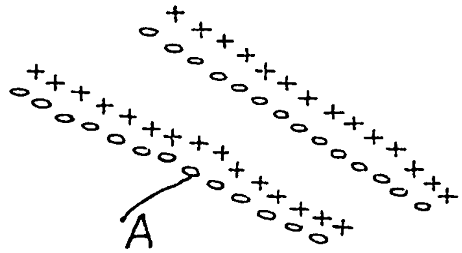

Fig. 9b

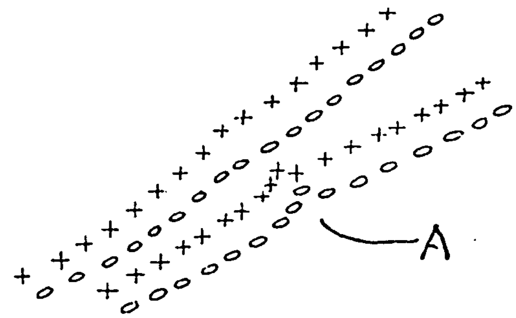

Fig. 9c

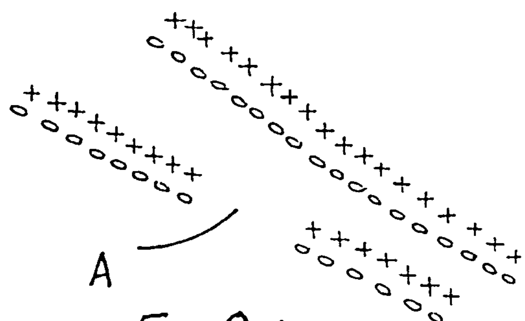

Fig. 9d

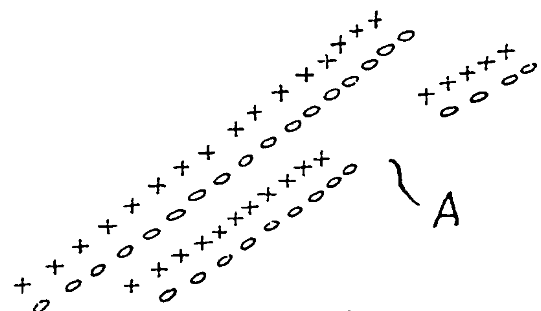

Fig. 9e

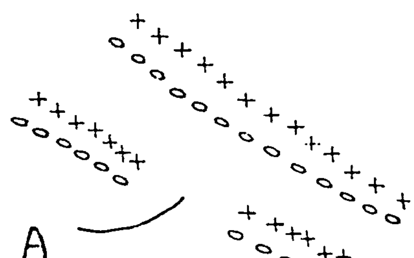

Fig. 9f

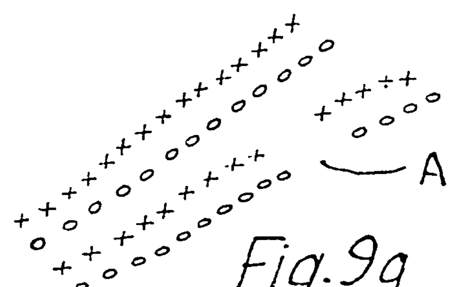

Fig. 9g

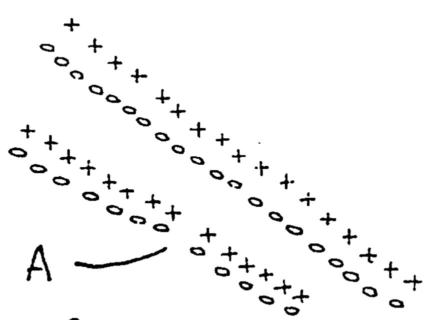

Fig. 9h

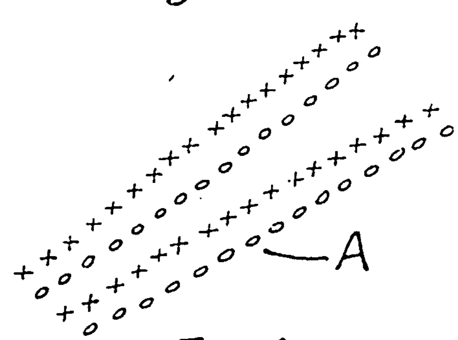

Fig. 9i

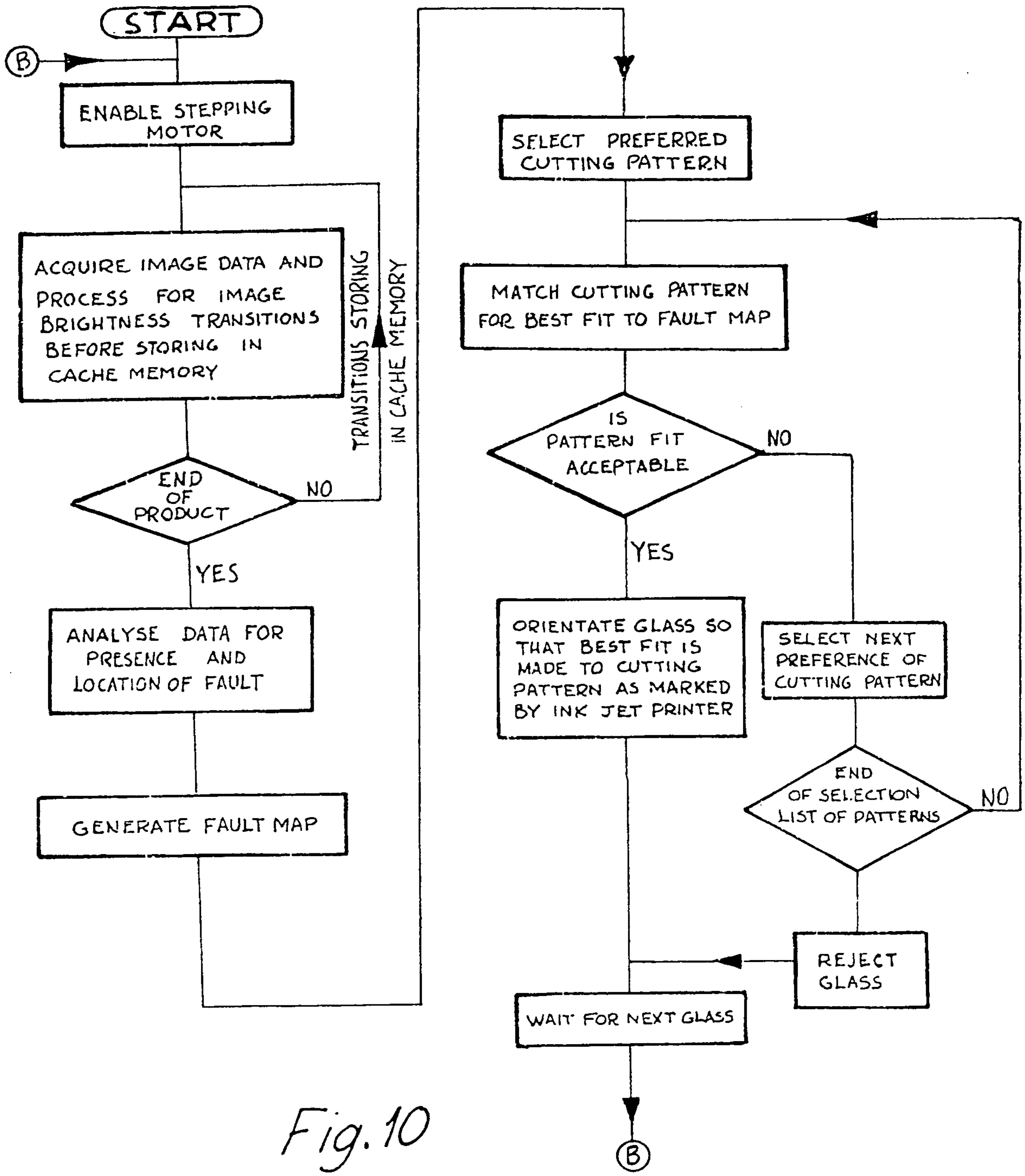
START
B
ENABLE STEPPING MOTOR
ACQUIRE IMAGE DATA AND PROCESS FOR IMAGE BRIGHTNESS TRANSITIONS BEFORE STORING IN CACHE MEMORY
TRANSITIONS STORING IN CACHE MEMORY
END OF PRODUCT
NO
YES
ANALYSE DATA FOR PRESENCE AND LOCATION OF FAULT
GENERATE FAULT MAP
SELECT PREFERRED CUTTING PATTERN
MATCH CUTTING PATTERN FOR BEST FIT TO FAULT MAP
IS PATTERN FIT ACCEPTABLE
NO
YES
ORIENTATE GLASS SO THAT BEST FIT IS MADE TO CUTTING PATTERN AS MARKED BY INK JET PRINTER
SELECT NEXT PREFERENCE OF CUTTING PATTERN
END OF SELECTION LIST OF PATTERNS
NO
REJECT GLASS
WAIT FOR NEXT GLASS
B

Fig. 10

SPECIFICATION

Improvements in an relating to glass inspection

The present invention relates to the analysis of the physical features of glass objects.

The term "glass object" includes any transparent or translucent object such as a finished or part-finished drinking glass, vase, bowl or decanter, and in particular glass objects which are subsequently worked for cut glass and the like. Hereinafter they are generally referred to as glass objects.

The term "physical features" is intended to cover the profile, thickness and composition of a glass object, and in particular, the presence or absence of faults. Faults can be simply air holes, occlusions or foreign matter on an outer surface, an inner surface or intermediate the two surfaces of a glass object.

A particular problem with cut glass is that the glass which is to be cut is hand-blown and often has a number of faults which mightn't necessarily be present in machinemade glass. Since the glass is subsequently cut, if the correct position for starting to replicate the pattern on the glass is chosen, then most of the faults may be cut out or effectively nullified during the cutting process. This is not as simple an operation as it seems and requires considerable skill. Heretofore, it has not been satisfactorily achieved and many glass blanks have to be rejected prior to cutting or indeed, the finished glass, decanter, vase, bowl or the like has to be rejected after cutting which is even more serious. To avoid the latter fault a considerable number of glass blanks are rejected that could in fact be utilised.

Further, the thickness of the glass blank can be significant as can it's profile. There might not be any "faults" as such in the blank but considerable variations in thickness or shape within the blank itself or between blanks of a set to be used together could be unacceptable.

The present invention is directed towards overcoming this problem and also to providing a method of checking the thickness of glass, irregularities in glass objects and so on hereinafter generally referred to as faults.

According to the invention there is provided a method of analysing the physical features of a glass object comprising the steps of:

projecting a beam of light onto the object;

detecting as an outer image the image of the beam on the outer surface of the object as it is being reflected from the outer surface;

detecting as a separate inner image the image of the beam on the outer surface as it is being refracted at the outer surface after refraction into the object and reflection from the next inner surface; and

analysing the outer and inner images to determine various physical features of the object.

Further, the invention provides a detection apparatus for analysing the physical features of glass objects comprising:

a light projector for directing a beam of light onto the glass object;

means for detecting as an outer image the image of the beam on the outer surface of the glass object as it is being reflected from the outer surface;

means for detecting as a separate inner image the image of the beam on the outer surface as it is being refracted at the outer surface after refraction into the object and reflection from the next inner surface; and

means for analysing the outer and inner images to determine various physical features of the glass object. The invention will be more clearly understood from the following description of an embodiment thereof given by way of example only with reference to the accompanying drawings in which:

Figs. 1 (a) to (i) are diagrammatic views showing the action of a beam of light on a glass object;

Fig. 2 is another view of a beam of light falling on a glass object illustrating thickness measurement;

Figs. 3 and 4 are views of a beam of light impinging on a surface irregularity;

Fig. 5 is a perspective stylised and diagrammatic form of an apparatus according to the invention in use, inspecting a glass object,

Fig. 6 is a plan view showing in diagrammatic form operation of the apparatus;,

Fig. 7 is a graph showing motion of the glass object and of a scanning beam of light;

Fig. 8 is a view showing portion of the ef fects of a scan as perceived by a camera used in the invention;

Figs. 9(a) to (i) are portions of a printout according to the invention; and

Fig. 10 is a flow chart of the operation of the apparatus.

The present invention provides a method of analysing the physical characteristics of a glass object. The essential principle of the invention is that a beam of light is projected onto the object and then the object is examined by means of a camera or other arrangement to detect

the images on the surface of the object. Essentially there will be two images. The first image is an outer image which is the image of the beam on the outer surface of the object as it is being reflected from that outer surface. The other image is a separate inner image which image of the beam is also on the outer surface but this image occurs after the beam of light has been refracted at the outer surface into the object where it is incident on the next inner surface and is then reflected from that inner surface and is then refracted at the outer surface again. Essentially the method of the invention is based on the analysis of these two images namely, the outer and inner images to detect the extent of the physical characteristics of, for example, glass thickness, surface irregularities and faults that may appear therein. While an apparatus is described hereinafter for carrying out the readily appreciated by anybody reading the subsequent description of the apparatus that many other forms of apparatus could be used.

For a clear understanding of the invention it is important to appreciate the rationale behind the analysis of the appearance or absence of these inner and outer images. Fig. 1 illustrates in diagrammatic form the principles of the method of the present invention.

Referring initially to Fig. 1(a) there is illustrated how a relatively narrow slit of light from a light source projected onto the object produces two separate images, namely, an outer image which is an image of the beam on the outer surface of the object as it is being reflected from the outer surface and an inner image, which is an image of the beam on the outer surface as it is being refracted at the outer surface after refraction into the object and reflection from the inner surface of the object.

Referring to Figs. 1(b) to 1(d) inclusive, it will be seen that if there is a fault on the outer surface it will firstly block the inner image as refraction is prevented at the outer surface. As the object rotates the fault will then be located between the path of the refracted beam and there are two images (see Fig. 1 (c)). Later both images will be absent as the fault prevents the light beam from being refracted into the object and from being reflected from the outer surface (see Fig. 1(d)).

Considering now the situation in which there is a small fault intermediate the two surfaces, as the object rotates it will firstly, block the light beam after it has been reflected from the inner surface (see Fig. 1 (e)), and so the inner image is absent. On further rotation both images will be present as the fault is between the path of the light beam as it is being refracted (see Fig. 1 (f)). When the object is further rotated the intermediate fault will again block the light beam after it has been refracted at the outer surface. The resulting absence of an inner image will be detected as being substantially identical to the initial absence of an inner image as the same fault is causing it.

An intermediate fault will not always cause two separate, substantially identical absences of the inner images.

Referring to Fig. 1(h), the angle of incidence ("i") and the angle of refraction ("r") are shown. It will be immediately apparent that any intermediate fault which subtends an angle at the inner surface greater than twice the angle of refraction will not cause two identical absences of the inner image, but merely one. The length ("1") of this fault thus varies depending on the distance from the inner surface (d) and the angle of refraction.

This may be expressed mathematically as:-

$$1 = 2d \tan r$$

The critical parameter therefore for inspection is the angle of refraction r.

Referring now to Fig. 1(i) there is illustrated the situation where there is a fault on the inner surface. This fault will cause one absence of the inner image and no absence of the outer image. It will be seen that the single absence of an inner image indicates either a fault on the inner surface or a fault intermediate the surfaces, which fault subtends an angle relative to the inner surface greater than twice the angle of refraction of the beam within the glass object as discussed above with reference to Fig. 1(h).

The above discussion of fault detection is by its very nature simplistic. It will be appreciated that there will be many inspections of the glass object and that this will be carried out by either indexing the beam relative to the glass object or indexing the glass object relative to the beam. The extent therefore, of a fault can be ascertained by the number of times a beam is interrupted and by the distance between each beam relative to the glass object.

There are however, other physical properties that should be ascertained such as the thickness of the glass object and any surface irregularities.

Referring to Fig. 2, when it is desired to measure the thickness (T) of a wall of a glass object, this can be readily done by the application of the following formula:

$$T = \frac{t \tan i}{\sqrt{\mu^2 - \sin^2 i}}$$

where

T = thickness of glass;

μ = relative refractive index;

i = angle of incidence; and

t = apparent thickness of glass (separation of images)

Referring to Fig. 3 there is illustrated in diagrammatic form the effect of an inner surface irregularity. Two beams are illustrated which, needless to say, will only happen when the glass object has been indexed. The first beam is shown by the full lines and the second beam is illustrated by the interrupted lines. It will be noted that an inner surface irregularity will not affect the outer images but will effect the inner images. Cross-over between the images will also occur.

Referring to Fig. 4, when there is an outer surface irregularity, it affects both the outer and inner images as shown. Thus, the analysis of what is happening can be quite complex though it will be appreciated that it is possible by analysis to understand what is happening. It is thus possible to programme the detection apparatus to make the necessary discrimination between the various types of surface irregularities etc.

Referring to Fig. 5 onwards of the drawings there is illustrated a detection apparatus, indicated generally by the reference numeral 1 for carrying out the method of the present invention, namely, analysing the physical features of a glass object, identified in the drawings by the reference numeral 2. The detection apparatus 1 comprises a turntable 3 mounted on a base 4 operated by a stepping motor (not shown). The detection apparatus 1 further includes a light projector 5 having a casing with a narrow vertical aperture 6 to form a narrow beam or slit of light. A mirror 7 is mounted on a vertically arranged pivot arm 8 which is oscillated by a motor, not shown;, mounted in a casing 9. A linear array camera 10 is mounted on the base 4 as is an ink jet gun 11. The camera 10 is a linear array camera in the form of a vertical longitudinal slit with discrete light sensitive elements. The apparatus is connected to suitable control and recording equipment 12 shown in block diagrammatic form. As the mirror 7 oscillates it, in effect, traverses or sweeps across a field of view of the glass object 2. For a drinking glass blank a typical field of view has a height of 9" and a width of 0.5". There are two distinct movements, the sweep of the mirror 7 and the rotation of the turntable 3 in discrete steps. The sweep of the mirror 7 is illustrated in Fig. 6. Two sweep lines are illustrated identified by the lines 16 and 16a for mirror positions 7 and 7a respectively. A slit of light 17 is then directed tcwards the camera 10, not shown in Fig. 6.

Fig. 7 illustrates against time the scanning mirror 7's displacement and the rotation of the glass object relative thereto.

Referring to Fig. 8 scan lines are identified by the reference numeral 20 and differentiated by different subscript letters as required. Each scan line 20 represents one image in the picture elements of the camera 10 of the glass object 2 identified by a particular register or reference position. Each scan line 20 has a camera address which is unique to it as will be explained hereinafter. The distance between the scan lines 20a and 20b represents the width of the field of view of the camera. The height of the field of view is shown on the vertical axis and in one embodiment is 9" with a width 0.75". The camera has vertical and horizontal resolutions of δy = 9 thousandths and δx = 5 thousandths of an inch respectively. For this resolution a thousand (9" × 9/1000") picture elements are required and one hundred and fifty (0.75" × 5/1000") scan lines are required. Accordingly, for an exposure time of 60 μs, the time taken for the camera to scan one field of view is 9 ms (150 lines × 60 μs/line). This gives a desired scanning frequency of 55 Hz for the mirror 7. The rotational resolution of the camera 10 is

0.25° and therefore the object 2 should rotate in at least 1,440 (360°/0.25°) steps per complete revolution. In practice, it has been found that a stepping motor having 2000 steps per revolution is satisfactory, even though this means that the glass object 2 will rotate while a field of view is being scanned.

Referring again to Fig. 6 the width of the light slit 15 is not a very critical parameter, at the same time it must be understood that:

(a) for precision, the light slit 15 should be as narrow as possible; and

(b) the light slit 15 should be wide enough to cover approximately 10 picture elements so that noise superimposed on the signal, and blur due to mirror and glass movement do not affect the detection of light; and

Referring to Fig. 8, at the scan line 20c at the height indicated by the reference numeral 40, there will be a change from darkness to brightness due to an inner image. The next change is from brightness to darkness at 41. The brightness detected between 40 and 41 is due to the width of the inner image. The outer image from the outer surface is seen higher up on the scan line 20c at 42 and 43.

The signal from the camera 10 is transmitted to a signal pre-processing unit in the control and recording equipment 12, which unit filters, amplifies and windows the video signal so that only selected parts of the image frame are analysed and a clear, strong signal is passed on for further processing. Edges or contours of the reflection images are then detected and narrow, spurious reflection images are eliminated. A computer, also forming part of the control and recording equipment 12 stores positions of edge points of the glass object. This information is then used to calculate defect positions in terms of, for example, vertical position, angular position and dimensions.

Referring to Fig. 9(a) there is illustrated in printout form the record of the camera images. Note that these are illustrated for ease of understanding but do not correspond physically to the scan lines 20c and 20d shown in Fig. 8. The horizontal scale at the bottom of Fig. 9(a) gives the camera addresses, indicated generally by the reference numeral 21, for the scan lines 20. The main point to appreciate is that the changes in light received by the camera in the scan line 20c having an address at 21c is the inner image between 40 and 41 the outer image between 42 and 43. It should also be noted that the direction of sweep in Fig. 8 is from right to left for the printout of Fig. 9(a) and in the opposite direction for the printout of Fig. 9(b) and so on.

Referring to Figs. 9(b) to 9(i) respectively, there is illustrated a fault causing a break in an inside reflection, for example, as identified by the arrow B in Fig. 8. The faults shown in Figs. 9 and 8 are not the same fault.

Fig. 9(b) shows the beginning of what appears to be some fault from an inside reflection which can be seen and identified by the arrow A. This becomes more pronounced in Fig. 9(c) and is now in Fig. 9(d) is identified by a complete break in the light which continues in Fig. 9(e) and 9(f) through Figs. 9(g) and 9(h) where it is beginning to disappear. In Fig. 9(i) it has almost disappeared.

Essentially, what is done is the curvature is analysed and stored and compared to the next curvature to see has there been an unacceptable change. As can be seen from Fig. 9 there is usually a warning of defect.

To ensure that an acceptable level of accepted rejection is achieved a sample of a number of different glass objects or blanks of the same shape are analysed so that acceptable and unacceptable defects can be classified and compared and categorised.

Fig. 10 illustrates in flow diagrammatic form one way in which the invention can be carried out. The diagram is largely self-explanatory, however, some comments are appropriate.

The first operation which the computer forming part of the control and recording equipment 12 performs is to find the first and the last data words in a data string (consisting of reflection contour positional information) which belong to the same image frame and determine whether that frame had been obtained for a clockwise ('Up' frames) or an anti-clockwise ('Down' frames) rotation of the mirror 7. This can be done by checking special code characters embedded in the information about the reflections.

The Up frames are then analysed in the normal fashion, line after line starting at the topmost part of the image and the Down frames are analysed starting from the bottom part of the image.

The next operation consists of splitting the combined images into two separate arrays and finding the outside edge positions for the outer image and the inner edge positions for the inner image. These two lines form the description of the glass shape.

Crystal glass, being a hand produced product, does not have a totally predictable shape which can be described mathematically. There are variations in glass height, inclinations of the sides, surface irregularities and variations in the thickness. It is not possible to produce a universal template of glass shape and then compare the shapes of the outer reflections of inspected glasses with the template. Accurate templates for inner reflections can not be produced due to significant variations in glass thickness.

Therefore, the templates of a glass under inspection must be produced continuously, from the inspection data itself, separately for each section of the glass.

This is performed by carrying out a filtering/smoothing operation on each of the image signals. The following gives a summary of further processing which is carried out on the signals:

(i) Each smoothed image signal is compared with the original image data—this results in a 'difference' signal which is small in the areas of glass where there are no faults and larger, with amplitudes increasing with the fault size, in the areas where glass is defective.

(ii) The difference signal is subjected to further processing by calculating the power in the difference signal for a number of neighbouring scan lines. The idea behind it is that if a fault is present, the difference signal value will be affected not just on one scan line but on a number of neighboring lines, and then the power signal will have large local values. On the other hand, if noise or a spec of dust are present large difference signals could be present on one or two scan lines only, and the effect of this on the power signal will be small.

The number of scan lines which are taken into account for the calculation of the defect power signal depends on the desired sensitivity of the equipment and the physical distance between the scan lines.

(iii) The values of the power signal, for each of the scan lines, are compared against a threshold value. The threshold value can be varied by the user (through a menu). This is equivalent to adjustment of sensitivity of equipment.

If the power signal is larger than the threshold value then a decision is made that a fault is present on that particular scan line, and its position in the camera array is used later for calculating the fault height.

(iv) Additional processing is associated with the monitoring of the widths of both images. This is important as in some instances the shape of the image outline may not be affected by a fault, but a narrowing or total blockage of the image.

(v) Results obtained from the analysis of each frame are stored in a special table. After the scanning of a glass has been completed the results table is analysed to eliminate small spurious 'defects', to calculate the extent of each fault in both rotational and the vertical directions and to determine whether the fault is on the inside, outside or intermediate the glass surfaces.

The invention is not limited to the embodiments hereinbefore described but may be varied in construction and detail.

CLAIMS

1. A method of analysing the physical features of a glass object comprising the steps of:
projecting a beam of light onto the object;
detecting as an outer image the image of the beam on the outer surface of the object as it is being reflected from the outer surface;
detecting as a separate inner image the image of the beam on the outer surface as it is being refracted at the outer surface after refraction into the object and reflection from the next inner surface; and
analysing the outer and inner images to determine various physical features of the object.

2. A method as claimed in Claim 1 in which a first inspection of the glass object is used to provide a datum record of the outer and inner images for comparison with subsequent images of that particular glass object.

3. A method as claimed in Claims 1 or 2 in which the profile in cross-section of the glass object is obtained by recording together the inner and outer images at discrete positions on the object.

4. A method as claimed in any preceding claim in which the absence of an inner image followed by the absence of both images indicates a fault on the outer surface.

5. A method as claimed in any of Claims 1 to 3 in which the absence of an inner image followed by an inner image, and then a substantially identical absence of another inner image indicates a fault intermediate the surfaces which fault subtends an angle relative to the inner surface less than twice the angle of refraction of the beam within the glass object.

6. A method as claimed in any of Claims 1 to 3 in which the absence of an inner image indicates a fault on the inner surface or a fault intermediate the surfaces when the said intermediate fault subtends an angle relative to the inner surface greater than twice the angle of refraction of the beam within the glass object.

7. A method as claimed in any of Claims 4 to 6 inclusive in which the additional step of physically marking the location of a fault on the glass object is performed.

8. A method as claimed in any of Claims 4 to 7 inclusive in which, when it is desired to cut the glass, the additional step is performed of comparing an unacceptable fault detected with a desired pattern to determine whether the fault can be cut out.

9. A method as claimed in Claim 8 in which the desired pattern is matched to the glass to give an optimum location of the pattern on the glass.

10. A method as claimed in any preceding claim in which the thickness of the object can be

obtained by the steps of:
measuring the thickness of the beam; and
recording the angle of incidence of the beam on the glass object.
11. A method as claimed in Claim 10 in which the thickness of the beam is

$$T = \frac{t \tan i}{\sqrt{\mu^2 - \sin^2 i}}$$

where

T = thickness of glass;

μ = relative refractive index;

i = angle of incidence;

t = thickness of light beam (separation of images)

12. A method of analysing the physical features of a glass object substantially as described herein.
13. A method of determining a cutting pattern for a glass object substantially as described herein.
14. A detection apparatus for analysing the physical features of glass objects comprising:
a light projector for directing a beam of light onto the glass object;
means for detecting as an outer image the image of the beam on the outer surface of the glass object as it is being reflected from the outer surface;
means for detecting as a separate inner image the image of the beam on the outer surface as it is being refracted at the outer surface after refraction into the object and reflection from the next inner surface; and
means for analysing the outer and inner images to determine various physical features of the glass object.
15. A detection apparatus as claimed in Claim 14 in which the means for detecting the images comprises in combination a linear array camera and an oscillating mirror for scanning the object to direct the image of the object into the camera.
16. A detection apparatus as claimed in Claim 14 or 15 in which the glass object is mounted on an indexing table.
17. A detection apparatus as claimed in any of Claims 14 to 16 in which there is provided an apparatus for physically marking the glass object when a fault is detected.
18. A detection apparatus as claimed in Claim 17 in which an ink jet printer is provided.
19. A detection apparatus for analysing the physical characteristics of a glass object substantially as described herein with reference to and as illustrated in the accompanying drawings.

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